arXiv:astro-ph/0109139v1 9 Sep 2001

Mg$_2$-σ in Early-Type Galaxies and Spiral Bulges

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Abstract. We analyze new measurements of the Mg$_2$ central line strength index and velocity dispersion (σ) for the galaxies of the ENEAR survey. The observations are now complete (da Costa et al. 2000) and the sample contains 1223 early-type galaxies. We also analyze the line strength indices for a sample of 95 spiral bulges (from Sa to Sbc). For the early-type galaxies we find: *i)* that the Mg$_2$-σ relation for Es and S0s are nearly the same, with both populations showing comparable scatter, and *ii)* a marginal difference in the slope of the Mg$_2$ and σ relation for cluster and field early-type galaxies. However, we suggest that before interpreting such a difference in the framework of a mass-metallicity relation, it is important to take into account the effects of rotation in the Mg$_2$-σ relation. Our preliminary results indicate that once the rotation effects are minimized by choosing a sample containing only slow rotators, the Mg2-σ relation is similar both for isolated and clustered galaxies. More data on rotational velocities of early-type galaxies are needed to confirm this result. For spiral bulges, we find that their locus in the Mg$_2$-σ plane lies always below the one occupied by early-type galaxies.

1.   Introduction

In this work we focus our attention on the Mg$_2$-σ relation presented by early-type galaxies (e.g. Terlevich et al. 1981) and its possible dependence on the environment as suggested by some authors. The goal is to investigate the existence of this difference and, if real, its possible cause. We also show a comparison of early-type galaxies and spiral bulges in the Mg$_2$-σ diagram. While there is growing evidence that at least the well studied bulges (Milky Way and M31) are old (Renzini 1999 and references therein), it is extremely important to investigate if bulges share the same chemical properties of E+S0s. For instance, Jablonka et al. (1996) and Idiart et al. (1996) found that bulges (from Sas to Scs) follow the same Mg$_2$-σ relation displayed by E+S0s. In this work we address the above questions by means of an analysis of Lick index measurements of integrated spectra of E+S0s and bulges which has proven to be important for studies of the formation and evolution of galaxies. The data will be presented elsewhere (Rité et al. 2001, Wegner et al. 2001).

2.   The data

The samples used in this analysis come from two surveys conducted by our group at Observatório Nacional (Rio de Janeiro) and collaborators. Early-type galaxies are primarily from the recently completed ENEAR redshift distance survey of da Costa et al. (2000), while the spirals are taken from SSRS2 sample (da Costa et al. 1998).

   The ENEAR project assembled spectroscopic and photometric data for early-type galaxies brighter than m$_B$=14.5, covering the whole sky. From these, 1223 galaxies have both spectroscopic and photometric data and were used in this analysis. Spectroscopic data for these galaxies yielded radial velocities, central velocity dispersions and several indices in the Lick system. Photometric data in the R band yielded total magnitudes, intensity profiles, bulge and disk characteristic scales, disc-to-bulge ratios, isophotal shape parameters and a characteristic diameter D$_n$ (Dressler et al. 1987). Moreover, by establishing an appropriate Dn-σ relation in the R band true distances were obtained for most of the objects in this sample. The ENEAR sample was split between field and group/cluster galaxies by using the membership assignment as described in Bernardi et al. (1998) (hereafter B98). In order to simplify the analysis we split the sample in two categories: isolated galaxies and clustered galaxies. The latter class combines groups and clusters and the two-fold separation basically represents low and high density environments. We note that as compared with the analysis of B98 there is an improvement in the group catalog used resulting in a more realistic distribution with environment namely, a larger number of clustered early-type galaxies.

   The sample of spirals comes from the Southern Sky Redshift Survey (SSR2 da Costa et al. 1998) down to a limiting magnitude $m_B = 15.5$. Here we only considered spirals earlier than Sbc and galaxies with central intensity ratios bulge/disk larger than 2. In the case of spirals, the integrated light at large radii is dominated by the disk, making an aperture correction procedure very uncertain. Therefore, spectral extraction of spiral bulges was done by varying

the projected aperture so as to preserve a fixed metric diameter of $1.19h^{-1}$kpc. A major concern in measuring the spectral properties of bulges of spiral galaxies is the effect of contamination of the integrated spectra by disk-light. We carried out many tests to estimate the level of this contamination (see Pellegrini et al. 2001b) and we concluded that the disk contribution in our integrated spectra is negligible.

3.   Early-Type Galaxies and the Mg$_2$-σ relation

3.1.   Mg$_2$-σ for field and cluster galaxies: slope difference

The ENEAR database yields the Mg$_2$-σ relation displayed in Figure 1a, where the data are split between isolated and clustered galaxies using the membership assignment mentioned before. In contrast with B98 (see below) we find a statistically significant (even though marginal) difference in the Mg$_2$-σ fit between the cluster and field samples (Figure 1a). As the sample includes both ellipticals and S0s, we also examine the possibility that morphology could be the cause of this difference. Splitting the total sample into ellipticals and S0s and performing a least square fit to the Mg$_2$-σ relation (see Figure 1b), we find that the resulting relations are essentially the same. Before interpreting the origin of this result and its and implications for the scenario of galaxy formation we need to consider further parameters that can affect the Mg$_2$-σ relation and as a consequence its interpretation as a mass-metallicity relation (section 3.3).

3.2.   Comparison with Bernardi et al. 1998

Instead of looking for a difference in the slope of the Mg$_2$-σ relation for clustered and field galaxies (as we did in section 3.1), B98 assumed a unique slope for early-type galaxies (obtained from the whole sample) and looked for a zero-point difference among galaxies belonging to different environments. These authors find a zero-point difference in the Mg$_2$-σ relation between cluster and field galaxies of ΔMg$_2 = 0.007 \pm 0.002$. Under the assumption of a fix slope, we also find a zero-point difference of 0.010 ± 0.002, in agreement with B98. A similar result was reported by Jorgensen (1997) who found ΔMg$_2 = 0.009 \pm 0.002$.

B98 concluded that the zero-point difference of 0.007 ± 0.002 found in the Mg$_2$ index would imply a difference in age of less than 1Gyr, field galaxies being younger. The important implication of this result is that if early-type galaxies were assembled through mergers, this process would have had to be fast, taking place at high redshifts.

3.3.   Mg$_2$-σ and the effects of rotation

Before discussing the origin of the result reported in section 3.1, lets consider the following arguments. It is usually assumed that the correlation of Mg$_2$ with velocity dispersion is equivalent to the more fundamental one: the mass-metallicity relation (Larson 1974). However, restricting ourselves to the velocity dispersion as a representation of galaxy masses, two relevant parameters are not being taken into account namely the characteristic size and the rotational velocity of the galaxies. Indeed, if a rotating galaxy is in equilibrium, the Virial

Theorem enables us to derive its total mass, by measuring some characteristic parameters related to internal dynamics and size as shown bellow:

$$M_{vir} = k(3\langle\sigma^2\rangle + \langle V_{rot}^2\rangle)R_e = k'\langle\sigma^2\rangle R_e(1 + (1/3)(\langle V_{rot}^2\rangle/\sigma^2)) \qquad (1)$$

where the quantities $\langle\sigma^2\rangle$ and $\langle V_{rot}^2\rangle$ are the effective values of the mean square line-of-sight velocity dispersion and the mean square rotation velocity, respectively, and R_e is the effective radius. After some simplifying assumptions, equation (1) can be written as (see Prugniel and Simien 1994):

$$M_{vir} = k'\langle\sigma^2\rangle R_e(1 + 0.81(V_{rot}/\sigma)^2) \qquad (2)$$

where k' $\simeq 2\times10^6$ if M_{vir} is in units of solar masses, σ and V_{rot} are in km/s and R_e in kpc. From the above expression it is clear that the Mg$_2$-σ relation represents a mass-metallicity relation only for slow rotating objects for which the approximation $M = k'\sigma^2 R_e$ is valid. Figure 1c shows this effect. In this figure, we plot all early-type galaxies from the ENEAR database for which rotational velocity measurements are available in the literature (HYPERCAT database by Prugniel and collaborators and Rix et al. 1999). The figure also shows the different fits obtained for objects with V_{rot} <50km/s (solid line) and V_{rot} >50km/s (dashed line). The slope difference found among fast and slow rotators is larger than the difference found when comparing different environments. In this figure (dotted lines) an estimate of the locus occupied by galaxies with V_{rot} = 50, 100 and 200km/s is also shown (see Pellegrini et al. 2001a). These curves represent an estimate of the effects of rotation in the Mg$_2$-σ relation and the main consequence is to produce a larger scatter at lower σ value (depending on details of the normalization adopted those dotted curves can be shifted up and down, so what is important here is their overall effect). As it is clearly seen from this figure, rotation moves data points to the right in the Mg$_2$-σ diagram. When splitting the objects with V_{rot} < 50 km/s into clustered and field galaxies, the Mg$_2$-σ relation does not seem to depend on environment, although this result should be confirmed using a larger sample.

In summary, although we find a difference in the slope of the Mg$_2$-σ relation among clustered and field galaxies, when considering the completed ENEAR sample, this result cannot be interpreted in the framework of a mass-metallicity relation unless the effects due to rotation are taken into account.

4.   Early-type galaxies vs Spiral Bulges and the Mg_2-σ relation

Figure 2 shows the fit for early-type galaxies with V_{rot} < 50km/s as well as the curves obtained when including rotation superposed on the distribution of early-type galaxies (panel a) and spiral bulges (panel b). In Figure 2b the open symbols correspond to the bulges in our sample and the crosses are the data by Prugniel et al. (2001). The agreement between both samples is remarkable. This figure shows that although bulges follow the same trend of increasing Mg$_2$ for increasing σ as E+S0s, a clear shift to the lower right region is seen. Moreover, the slope of the Mg$_2$-σ relation for bulges is steeper than the one found in early-type galaxies. Only massive bulges seem to have Mg$_2$ line strenghts comparable with E+S0 galaxies.
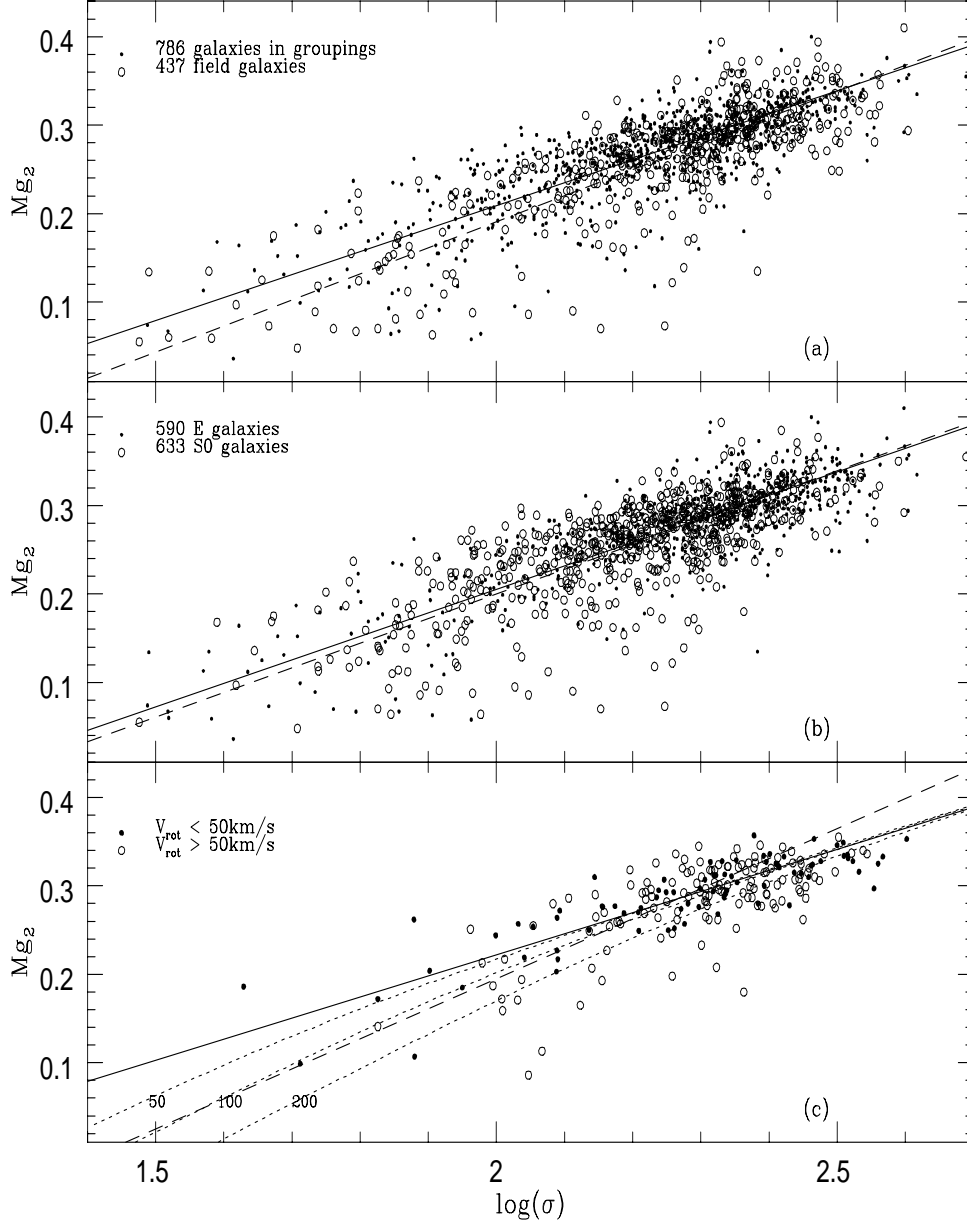
Figure 1. Mg$_2$-σ relation obtained from ENEAR database: a) for cluster E+S0s (dots) and field E+S0s (open circles). resampling). Orthogonal least-square mean fits with bootstrap resampling are shown for galaxies in groups/clusters (solid line) and in the field (dashed line); b) the same as a) but now instead of dividing the objects according to the environment, we slit the sample into ellipticals (fit shown by a solid line) and S0s (fit shown by a dashed line); c) same as in a) but only for galaxies that have measured rotational velocities. The sample was divided into slow (solid line fit) and fast rotators (dashed line fit). The dotted lines show the locus of the solid line in case a rotational velocity of 50, 100 and 200 km/s was considered.
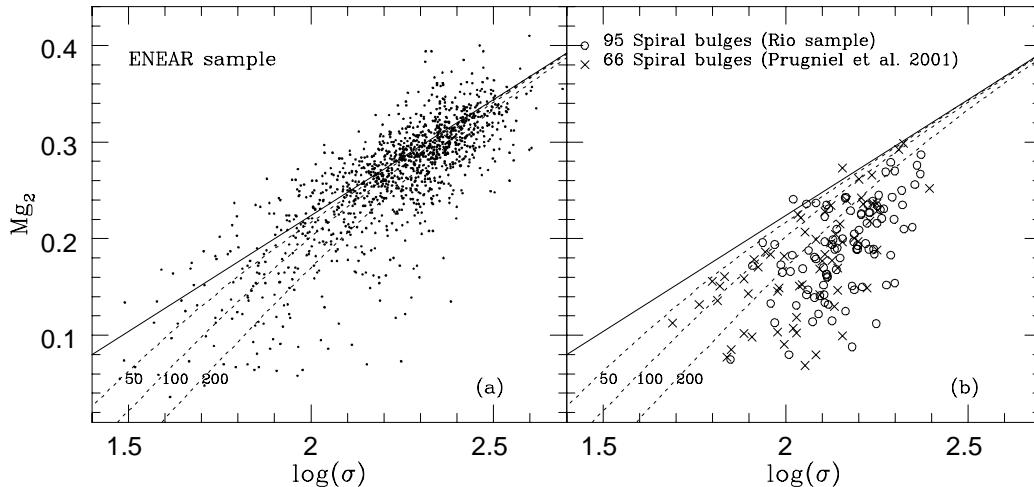
Figure 2.   Mg$_2$-σ relation traced by a) early-type galaxies b) by the
bulge data sample present here (open circles) and Prugniel et al. (2001)
sample (crosses). Lines are the same as shown in figure 1c.

Our findings are in close agreement with the recent results reported by
Prugniel et al. (2001). Both results are in contrast with earlier conclusions of
Jablonka et al. (1996) based on a much smaller sample of spiral galaxies than
the one considered here. The amplitude of the effect is considerably larger than
the small offset to lower line strengths for the bulges noted by some authors
(e.g. Wyse et al. 1997 inspecting the same data) and qualitatively similar to
the results of Balcells and Peletier (1994) who find that bulges and ellipticals of
the same luminosity do not have the same color, with bulges being bluer.

Part of this difference can be artificially caused in an Mg$_2$-σ plane since
rotation is improperly ignored (bulges are known to be fast rotators). However
another reason for this difference can be related to differences in their chemical
evolution and by the contamination of the bulge population by younger stars
(secular evolution and later infall). By analyzing preliminary results based on
the iron index, $\langle Fe \rangle$, we find that although early-type galaxies do not show a
significant relation between $\langle Fe \rangle$ and $\log \sigma$, bulges do show a clear correlation
between those quantities (exactly the same result found by Prugniel et al. 2001)
showing that bulges and early-type galaxies show different chemical properties.

5.   Discussion

In view of the above results, we suggest a possible scenario for the formation
of spheroids to be tested. We suggest that the formation of early-type galax-
ies occurs from a gas cloud in which gravity is acting to produce its collapse
and primordial angular momentum of the cloud tends to retain gas in the outer
parts of the system, which can later fall back into the system. A rapid initial
collapse (involving all protogalaxy mass or a large fraction of its inner portions)

will produce a spheroid (older stars) and later infall of gas may contribute to contaminate such an old population by a younger one. If a galaxy resides in a low density environment, free from gas stripping, this contamination will be more efficient and those galaxies would now show a low Mg$_2$ index (as a consequence of the addition of gas and the formation of a non-dominant younger population). On the other hand, if the galaxy is in a high density environment the gas in the outer parts of high rotation objects would be removed by the frequent encounters, inhibiting the infall that could cause further star formation. Moreover, galaxies with low rotational velocities would have had a more efficient collapse and hence their evolution would be less dependent on the environment. To test the above scenario one would need to verify if: *i)* the Mg$_2$-σ relation for slow rotators is the same in field and clusters; *ii)* the Mg$_2$-σ relation for fast rotators is very different in field and clusters; *iii)* fast rotators in the field show larger Hβ index values as compared with fast rotators in clusters.

The observational differences concerning line strength-velocity dispersion relation of bulges and ellipticals can also be understood in this same scenario, bulges being the extreme in the sequence of increasing rotation. However in this case the differences would also be a result of different chemical evolution and later contamination by a younger population. This is likely to happen as we expect some degree of cross-talk between disks and bulges.

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